(12) UK Patent Application (19) GB (11) 2 215 152 (13) A

(43) Date of A publication 13.09.1989

(21) Application No 8802420.3

(22) Date of filing 03.02.1988

(71) Applicant
Secretary of State for Defence
Whitehall, London, SW1A 2HB, United Kingdom

(72) Inventor
Henry William Hawkes

(74) Agent and/or Address for Service
R F Smith
Procurement Executive, Ministry of Defence, Patents 1A(4), Room 2014, 20th Floor, Empress State Building, Lillie Road, London, SW6 1TR, United Kingdom

(51) INT CL⁴
H03C 3/00 1/00

(52) UK CL (Edition J)
H3R RAMA RFMA R15G3X

(56) Documents cited
None

(58) Field of search
UK CL (Edition J) H3R RAMA RAMX RFMA RFMT
INT CL⁴ H03C

(54) Frequency-domain modulator circuit

(57) A circuit for generating a complex modulated signal including means (25, 26) for generating a carrier structure consisting of two or more out-of-phase (e.g. quadrature) signals at one or more different frequencies, means (18a, 18b) for generating one multiple spectral line modulation structure for each modulating frequency and each out-of-phase signal, means (23, 24) for multiplying each modulation structure with a corresponding out-of-phase signal and means 927) for adding corresponding spectral lines to synthesise the required frequency, phase and amplitude of the modulated signal.

Means are provided for the individual control of the separate lines in each modulation structure so that by generating the carrier structure by frequency division of multiplication from a single input signal a complex, for example wideband FM, signal may be generated from a single rf source having the stability of that source.

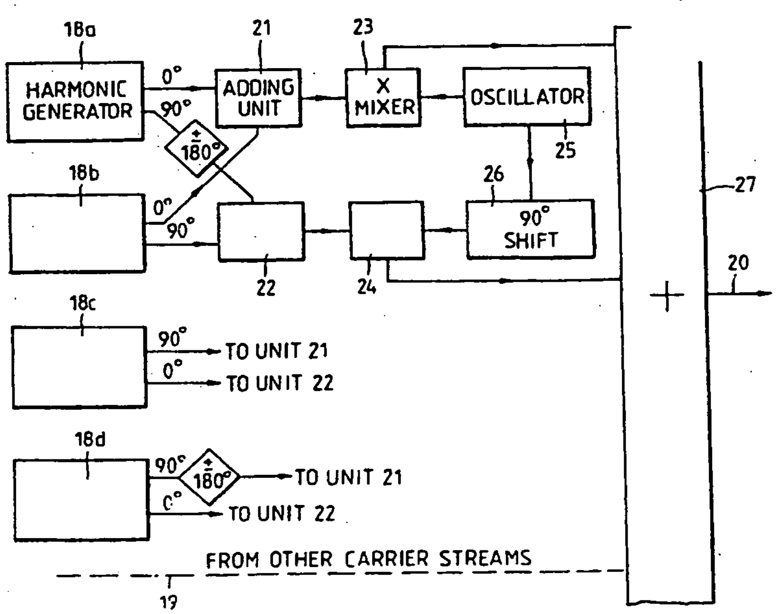


Fig.4.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

GB 2 215 152 A

2215152

Fig.1.

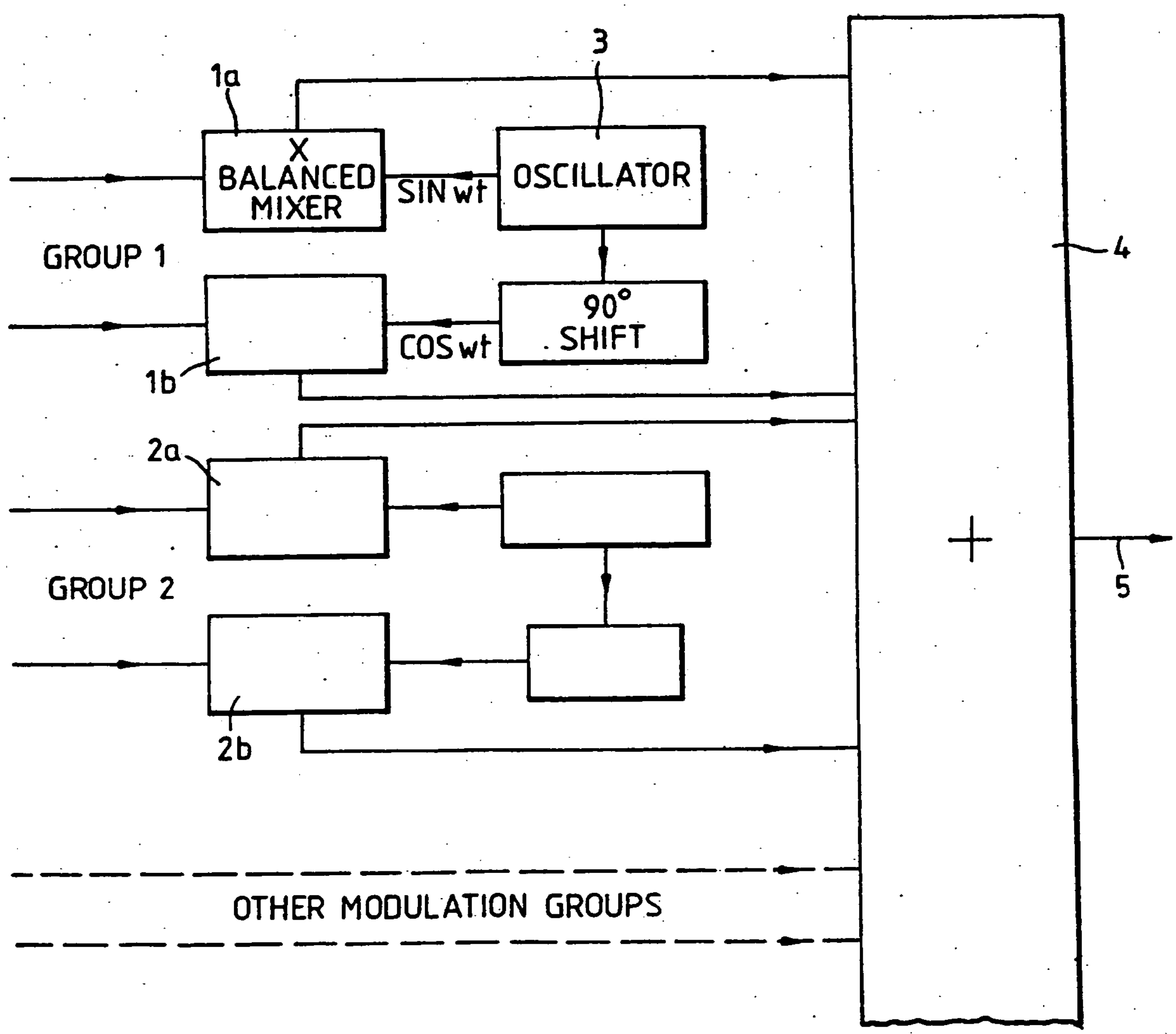
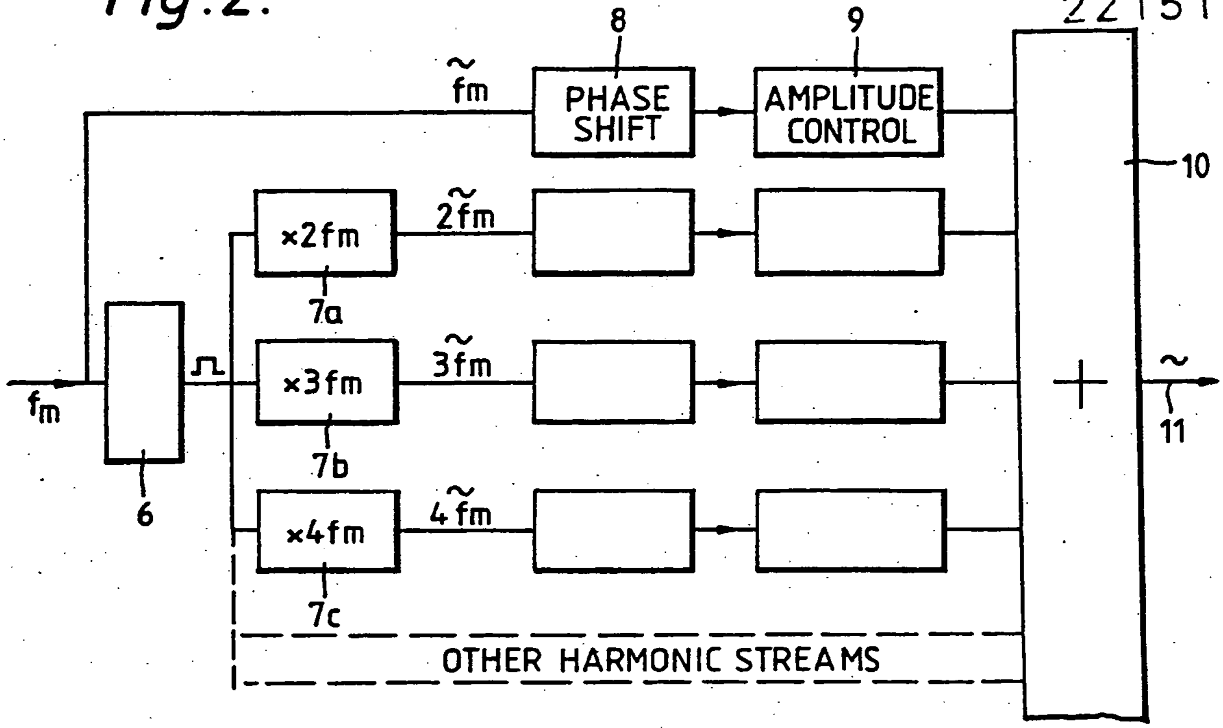
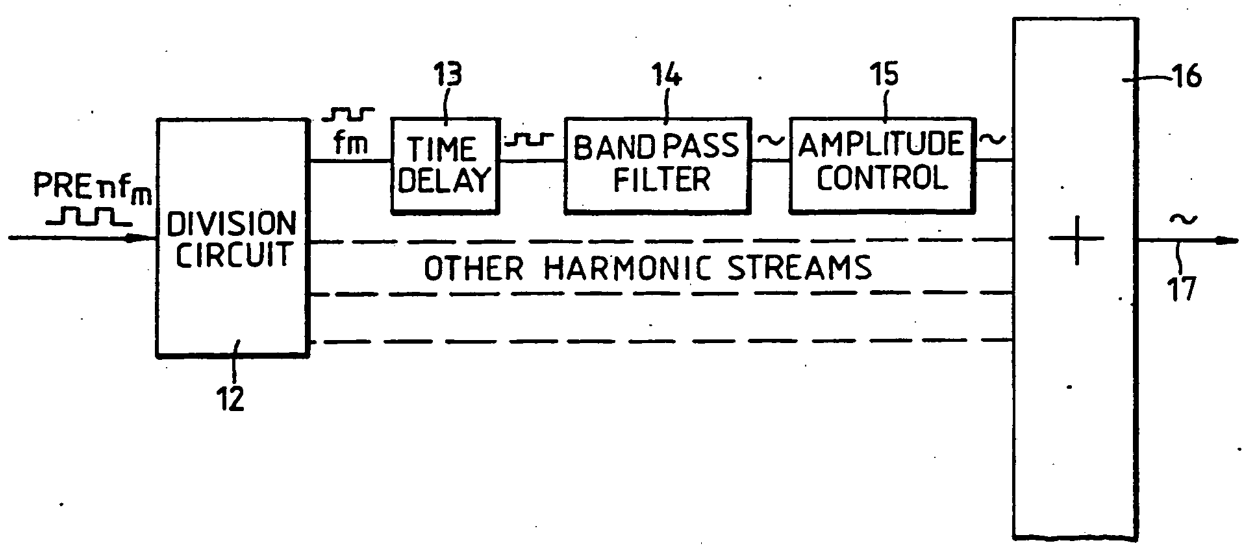


Fig. 2.



8
9
PHASE SHIFT
AMPLITUDE CONTROL
fm
2fm
3fm
4fm
×2fm
×3fm
×4fm
7a
7b
7c
6
10
+
11
OTHER HARMONIC STREAMS

Fig. 3.



13
14
15
16
PRE nfm
fm
DIVISION CIRCUIT
TIME DELAY
BAND PASS FILTER
AMPLITUDE CONTROL
+
OTHER HARMONIC STREAMS
12
17

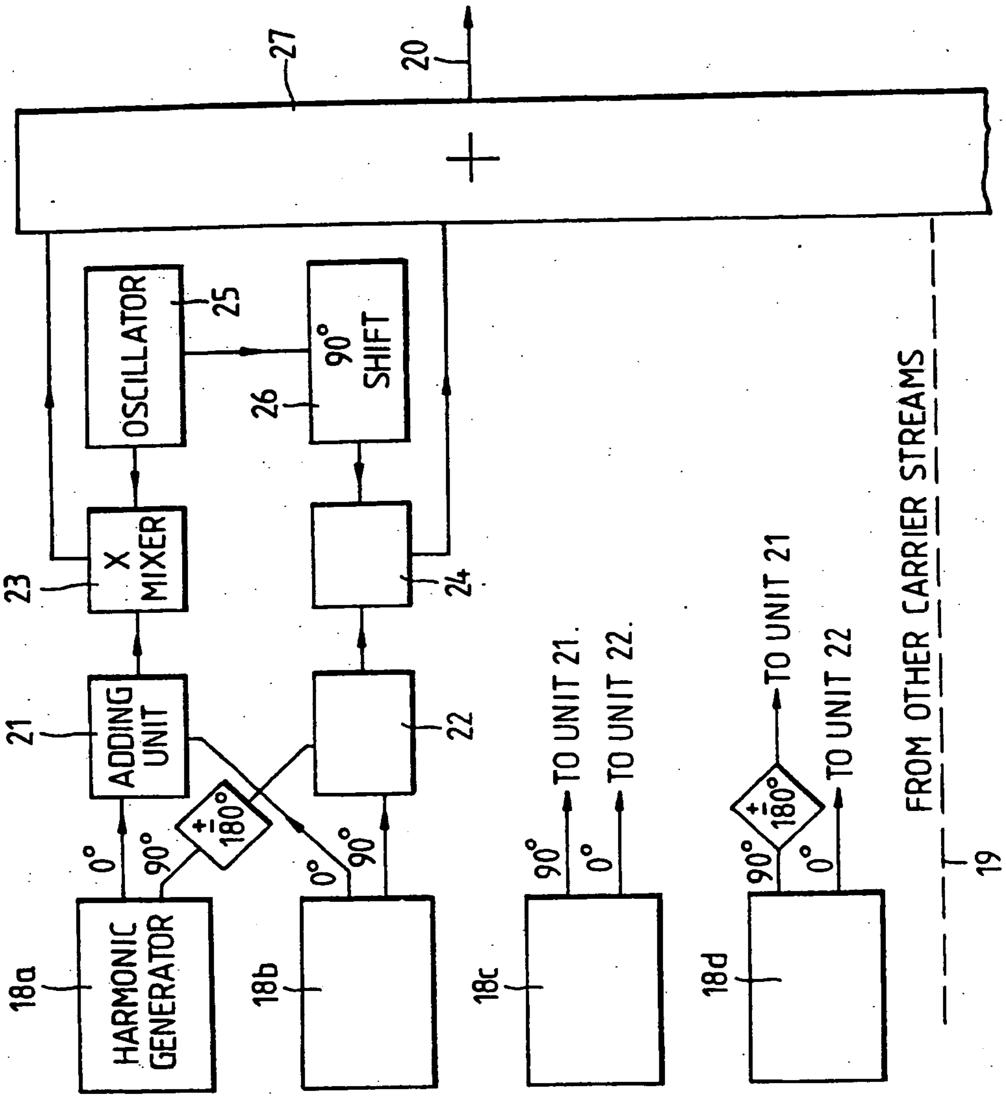

27
20
+
OSCILLATOR
25
90° SHIFT
26
X MIXER
23
24
ADDING UNIT
21
22
÷180°
0°
90°
HARMONIC GENERATOR
18a
18b
18c
18d
TO UNIT 21.
TO UNIT 22.
TO UNIT 21
TO UNIT 22
FROM OTHER CARRIER STREAMS
19

Fig. 4.

2215152

FREQUENCY DOMAIN MODULATOR CIRCUITS

This invention relates to modulator circuits, and provides a method of generating a modulated signal of any degree of complexity, with or without its nominal carrier wave, by synthesising the multiple sideband configuration by which the modulated signal can be expressed.

The invention is mainly of use for wideband modulation transmissions, typically those of the spread spectrum or multiple sub-carrier type, having an underlying structure that is fixed. The simplest fixed structure is probably that of wideband binary phase shift keying which consists, over a period of time, of a defined bit rate. Because of the imposition of non-fixed information modulation the overall effect seems complex but it still has a simple fixed bit rate structure although, at times, only sub-harmonics of the bit rate may be apparent. On the other hand, one of the most complex forms of wideband modulation, having a fixed structure, is that of compressive 'chirp' radar. In this case the time-variant information, imposed in terms of target position and/or rate of change of this position, does not add much additional complexity to the overall modulation structure which will then appear, at first sight, to be of a fixed variety.

These types of signals generally use well-established methods of modulation in the form of special-to-purpose circuitry and/or software processes. However, a more generalised process, which allows individual control of each

sideband of the modulated signal, in which frequency stabilities could be defined by a highly stable source or sources regardless of the form of the modulation, could be used to advantage in some applications.

As mentioned, the invention is concerned with complex modulated waveforms (but forming complex sub-carrier structures) but in describing these it is necessary to consider the basic modulation formats upon which they are built.

The simplest form of modulation is amplitude modulation in which the mean phase of the symmetrical sidebands is in phase or antiphase with the carrier. Possibly the next simplest form is that of narrow deviation frequency modulation in which the mean phase of a single pair of symmetrical sidebands is in phase quadrature with the carrier. Single sideband modulation is mathematically formed by a linear combination of both the above, but where the phases of the two original modulating tones are in phase quadrature to each other.

Over-amplitude modulation (ie over 100% modulated) leads to a series of pairs of symmetrical sidebands with harmonic modulating relationships between each symmetrical pair; all the mean phases are in phase with each other and the carrier. In the limit, the over-modulation produces a pulse-modulated carrier with the sideband structure having a $\frac{\sin \chi}{\chi}$ form.

Wideband frequency modulation produces a structure similar to that of over-modulated AM except that pairs of modulated harmonically-related sidebands are produced that have a quadrature mean phase relationship with the carrier; this is in addition to similar pairs having a co or antiphase relationship. In general, any modulation about a defined carrier will produce pairs of sidebands that can be grouped into those having either a quadrature or a co/antiphase structure. It does not follow that a carrier need always be present; wideband FM is a case in point, as is single sideband as well as phase-shift keying over given periods. There could be more than one modulating frequency which are not

harmonically related to each other. Finally, the carrier itself could be modulated in amplitude, frequency, phase or time and there could be multiple carriers, so that there could be quadrature/co/antiphase sideband structures around each real or suppressed, modulated or unmodulated carrier.

This invention therefore consists of a circuit for generating a modulated signal comprising: means for generating a carrier structure consisting at each of one or more frequencies of two or more carrier component signals having a different phase from one another; means for generating at least one multiple spectral line modulation structure at each of one or more modulating frequencies for each carrier component signal, each modulation structure having an individual spectral distribution; means for controlling the phase and amplitude of the separate lines in each modulation structure; means for multiplying each carrier component signal with a different modulation structure; and means for adding the resulting corresponding spectral lines to synthesise the required frequency, phase and amplitude of the modulated signal.

This invention thus provides a circuit capable of generating a modulated signal having a general complex structure which is primarily fixed although capable of being varied (ie modulated itself) by another signal (delivered as information). The structure, which is not necessarily based on a single modulating frequency and its harmonics, contains a plurality of sidebands and carriers and the invention provides individual control of the phase, frequency and amplitudes of these, not only for the purpose of generating the structure but also, if required, for modulating this structure with information signals. The circuit can be simplified if individual control is not required; ie, if sets of sidebands in certain pre-defined patterns are to be provided.

The use of a carrier structure which has phase quadrature components is basically the simplest form in a similar way as,

more generally, the X-Y cartesian way of expressing a two-dimensional relationship is the most convenient graphical form. Other related ways could be used, corresponding to non-perpendicular axes, but in most cases, these will result in more than two carrier samples being required. For simplicity, therefore, actual embodiments of this invention will be described with components in quadrature (cartesian) form.

The outputs from the circuits correspond to co/antiphase and quadrature phase sidebands and may readily be added to the outputs from similar circuits to generate a further and more complex modulation pattern containing multiple carrier frequencies. Each carrier signal may conveniently be generated by a stable rf oscillator whose output may be applied, where necessary, via separate modulators and/or a phase shift unit, to each balanced mixer so that an entire complex carrier/sideband structure may be generated using a single stable source, or independent or mutually locked sources if a multiple carrier structure is required.

Each fixed modulation structure, as defined, may be modulated itself by internal or external sources. In the former case, the modulation could be of a time-variant nature or by fixed/semi-fixed shifts in amplitude, phase and frequency of the fixed modulation structure. In the latter, the modulation would typically arise say as in Radar via reflections from movements or modulations of target position.

A modulating signal forming the fixed structure applicable to this signal may take the form of a sinusoid with its associated plurality of harmonics or sub-harmonics generated by a harmonic generator which may include means for controlling the phase and amplitude relationship between the harmonic components of the signal.

By way of example, embodiments of the invention will now be described with reference to the drawings, of which

Figure 1 is a schematic diagram of the simplest circuit arrangement according to the invention and capable of generating one or more symmetrical sideband modulated signals containing a plurality of sets of sidebands each sideband having by itself or in combination with another an appropriate phase relationship with a nominal carrier,

Figure 2 is a schematic diagram of a circuit for generating a stream of harmonically-related modulation signals by frequency multiplication and to be used in Figures 1 and 4 as appropriate.

Figure 3 is a schematic diagram of a circuit for generating a stream of sub-harmonic modulation signals by frequency division, and to be used in Figures 1 and 4 as appropriate,

Figure 4 is a schematic diagram of the full circuit according to the invention and incorporating a number of circuits similar in embodiment and purpose to that illustrated in Figure 1 but capable of generating a series of individual sidebands each having any desired amplitude, frequency and phase relationship with respect to a given carrier.

In the embodiment shown in Figure 1, a number of input carrier-modulating signals denoted as Group 1, Group 2 etc (one group for each carrier) are each fed into corresponding balanced mixers 1a, 1b, 2a, 2b etc.

Since each carrier modulation signal is processed in exactly the same way within the circuit, the operation of the circuit can be described using just one signal, for example one component of Group 1. This group may furthermore be conveniently expressed as

$$A_o + a_1 \sin (w_m t + \phi_1) + a_2 \sin 2(w_m t + \phi_2) \text{ etc}$$

where A_0 is a DC term and will represent the carrier element of

the modulation signal and the other terms are modulating sinusoids with various controllable amplitude and phase parameters as expressed by a_1 and ϕ_1 etc.

This part of the Group 1 signal is multiplied in the balanced mixer 1a with the carrier structure generated by an rf oscillator 3, one output of which is represented by a sin wt factor.

Thus the rf output of mixer 1a can be expressed as

$$A_0 \sin wt + a_1 \sin(w_m t + \phi_1) \sin wt + \ldots$$

which corresponds to a carrier plus a co/antiphase symmetrical sideband structure.

Similarly, the other part of the modulation structure of Group 1 as expressed by

$$B_0 + b_1 \sin(w_m t + \theta_1) + b_2 \sin 2(w_m t + \theta_2) \ldots \text{etc}$$

(b_1 and θ_1 not necessarily being identical to a_1 and ϕ_1) is multiplied in the mixer 1b, together with the oscillator output cos wt to produce a quadrature sideband structure based on a cos wt rf term, ie $B_0 \cos wt + b_1 \sin(w_m t + \theta_1) \cos wt$. The $B_0 \cos wt$ could still be present if required although in practice this would normally be set to zero by marking $B_0=0$ so that the quadrature structure can be said to be in mean quadrature phase with the carrier of $A_0 \sin wt$.

Although the above expressions describe a fixed modulation, in general the modulation could itself be modulated in the manner of many spread spectrum transmissions, and the signal can still be expressed as the sum of components in the form of a single carrier plus a sideband structure.

With reference again to Figure 1, therefore, any number of modulation groups 1, 2 etc, each group not necessarily having the same modulating frequency, can be combined in an adder (or subtractor) 4 to provide an rf output 5 comprising the sum of all sin wt and cos wt terms, the oscillator for each group generating and representing a different carrier frequency.

Furthermore, any number of modulating signals with their appropriate harmonics can be fed into a given carrier-based arrangement to form multiple modulation structures about the given carrier. This would involve the addition of a number of groups (say Groups 1(i), 1(ii) etc) before application to 1a and 1b.

The derivation of the series of harmonically related components $a_1 \sin w_m t$ etc with their appropriate amplitude and phase controls can be achieved by the circuit illustrated in Figure 2.

In this arrangement, a signal of basic modulating frequency fm is passed through a harmonic generator 6 to selective filters 7a, 7b, 7c etc tuned to the appropriate harmonic. Each filtered harmonic is then phase and amplitude-controlled by units 8 and 9 before being re-combined at a mixer 10 to form a modulating output at line 11 which can then be applied to one or more of the balanced mixers as in Figure 1.

Alternatively, a series of sub-harmonics may be generated by the circuit illustrated in Figure 3. In this circuit, a pulse stream of $\frac{1}{nfm}$ of the pulse repetition interval is generated by firstly dividing the input nfm signal by unit 12 to provide outputs, one for each harmonic of fm. Each output is then passed through a time delay shifter 13 for control of the relative signal phases to a selective filter 14 to isolate the appropriate harmonic. After passing through an amplifier 15 for amplitude control each signal is re-combined with the other harmonic streams at mixer 16 to provide a modulating output at line 17 which can again supply an input to the Figure 1 mixers.

Both Figure 2 and Figure 3 circuits provide individual phase and amplitude control of each sideband. Common control of all sidebands can be achieved via common information fed to all phase and amplitude controls, though it may sometimes be more convenient to apply a phase control at the input

designated f_m in Figure 2 or nf_m in Figure 3 in order to achieve a proportional phase delay on each harmonic.

The above arrangements treat the modulated signal or multiple modulated signals as being symmetrical about a carrier or multiple carriers. These are probably suitable for many fixed modulation structures. They would not be suitable for single sideband structures or for those requiring some degree of asymmetry; eg a structure with an inherent pre-equaliser programme of sideband variation to take care of anticipated dispersion in transmission and/or processing. In this sense, although providing a useful arrangement in its own right, the Figure 1 embodiment may be regarded as a degeneration of the full invention in which full individual control of each sideband is achieved via control of each modulating spectral line; ie in which a symmetrical sideband structure is no longer required.

The circuit illustrated in Figure 4 however provides a complete generalised modulator which is capable of generating any required sideband structure with individual control of each sideband, and consists of groups of up to four harmonic generating units 18a, b, c and d at each modulating frequency for generating complementary modulation patterns, together with the facility for combining their output with that from other carrier streams on line 19 to produce an rf output on line 20. It will be appreciated that the filters 7 in Figure 2 or the division circuit 12 in Figure 3 need not be duplicated for each one of the four generators but can be shared.

The four units 18a, b, c and d may be similar to those described with reference to either Figure 2 or Figure 3 except that two modulation structure outputs are available from each, one in phase quadrature with respect to the other, this being achieved by duplication of the respective phase and amplitude controls plus additive networks in Figures 2 and 3 or alternatively by a series of quadrature phase shifters for each controlled harmonic output in Figure 2 or 3 plus an appropriate adding network. Otherwise, the modulation frequencies are

controlled in phase and amplitude as described above.

The outputs from units 18a and 18b are combined in two adding units 21 and 22, the in-phase outputs of the generating units being applied to adding unit 21 and the quad phase outputs to unit 22, the quadrature output from 18a being subjected to a 180° phase shift. The output from each adding unit is then applied to a respective one of two balanced multiplying mixers 23 and 24 where they modulate a signal from an rf oscillator 25, a 90° phase shift 26 being applied to the rf signal applied to the mixer 24.

The outputs from the mixers 23 and 24 are then combined with each other in an adder 27 to produce an rf output on line 20.

To show the effect of the circuit portion so far described, the two outputs from the unit 18a, as fed into units 21 and 22, can be expressed as

$$A_1 + a_1 \sin (w_m t + \phi_1) \text{ plus harmonics of } w_m \text{ etc}$$

and $-a_1 \cos (w_m t + \phi_1)$ plus harmonics of w_m etc after being subjected to the 180° phase shift.

If, for the moment, the inputs from 18b are ignored then corresponding outputs from the balanced mixers 23 and 24 are therefore

$$A_1 \sin wt + a_1 (\sin w_m t + \phi_1) \sin wt + \text{etc etc}$$

and

$$-a_1 \cos (w_m t + \phi_1) \cos wt + \text{etc etc}$$

respectively, where w is the rf oscillator frequency.

The composite output from these on line 20 after being combined in adder 27 is therefore

$$A_1 \sin wt + a_1 \cos \left((w + w_m)t + \phi_1\right) + a_2 \cos \left((w + 2\, w_m)t + 2\phi_2\right) + \text{etc}$$

Thus, a quadrature phase single sideband operation has been performed on the sinusoidal modulation to provide an

upper sideband structure (as expressed by $w + w_m$, $w + 2w_m$,etc)

Similarly, the outputs from the unit 18b, as fed into units 21 and 22,

$$\bar{a}_1 \sin (w_m t + \bar{\phi}_1) + \text{etc}$$

and

$$\bar{a}_1 \cos (w_m t + \bar{\phi}_1) + \text{etc}$$

are processed and combined to form the lower sideband expressed by the terms

$$\bar{a}_1 \cos \left((w - w_m)t - \bar{\phi}_1\right) + a_2 \cos \left((w-2w_m)t-2\bar{\phi}_1\right)\text{etc}$$

where the bar terms a_1 ϕ_1 etc are used to indicate that the coefficients are not necessarily identical to the original a_1, ϕ_1 etc. No DC terms are required since in this analysis the carrier is assumed to be that of the A_1 term.

The circuit so far has therefore generated a carrier and upper and lower sidebands (which may not all necessarily be present). The sidebands are in mean phase with the carrier if (and only if) the sidebands are symmetrical and (ie $\phi_1 = \bar{\phi}_1$; $\phi_1 = \bar{\phi}_1$ etc) and such a case (eg the Figure 1 embodiment) is notated as a restrictive case.

By a similar analysis as before, the sidebands produced by generating units 18c and 18d in this way can be shown to be

$$b_1 \sin \left((w + w_m) t + \theta_1\right) + b_2 \sin \left((w + 2w_m)\right)t + 2\theta_1) \text{ etc}$$

and

$$\bar{b}_1 \sin \left((w - w_m)t - \bar{\theta}_1\right) + \bar{b}_2 \sin \left((w - 2w_m) t - 2\bar{\theta}_1\right) \text{ etc}$$

These quadrature components are similar to those generated from units 18a and 18b except for the nominal mean quadrature phase relationship with the carrier in respect of the restrictive case. The provision of a carrier from units 18c and 18d is not necessary. In this connection the provision of a carrier from units 18a and 18b may not always be required; eg for certain modulation indices of wideband FM/PM, carriers will not be present and therefore need not be generated.

Duplication of harmonic generators 18, if other modulation

frequencies are required, will need appropriate changes to f_m or nf_m. As already mentioned, when $\bar{a}_1 = a_1$, etc, the case becomes the restrictive one of Figure 1. In the more general case, lack of equality in the coefficients will cause 18a and 18b (or 18c and 18d) generators to produce symmetrical sideband spectra in line with both mean phases of the carrier. Thus the composite symmetrical spectra could be generated via a restrictive arrangement once the coefficients of the new symmetries are known. In this light the main disadvantage of the general case (Figure 4) over the restrictive one is greater complexity. The advantage is a greater capacity to control directly each spectral line in terms of phase and amplitude without the need for a multitude of calculations beforehand. However, with the advent of fast micro-processors a Figure 1 arrangement could be operated to virtually the same effect.

By means of this invention, whether in a restrictive or general arrangement, the form of modulation and/or carrier can be quickly changed to take advantage of particular circumstances. For example, a given spectral line, or a given one, more or all modulation tones, could be enhanced, eliminated or changed in phase, all in a fixed, cyclic or random manner.

In consequence, a programmed change of phase of each modulation component and carrier can be made such as to allow the whole signal to be appeared to be delayed by a given amount. This change can be fixed or variable on a cyclic basis. Furthermore, the phase changes can be dispersive in nature and accompanied by amplitude changes. The whole represents a possibility of providing pre-transmission equalisation before receiver detection processes. The whole arrangement could be used in a complex programmable jammer or anti-jammer arrangement. An important benefit from the invention is that the carriers and entire rf structure can be determined by either a single stable source or two sources, one for the carrier and one for the modulation. This would, for

example, allow a wideband FM signal to be given the stability of the source, normally quite difficult to achieve. It is also relatively simple to change the carrier or multiple carriers and/or the sub-carrier modulation structure or structures to new values in order, for example, to produce frequency diversity or frequency hopping facilities in the carrier and/or sub-carriers.

In the case of a single stable source modulation frequency is generated from w_m by division and/or mixing a crystal controlled frequency with the carrier source. Alternatively the carrier frequency itself could be derived via a multiplication of the modulated frequency. In the case where the carrier and the modulated sources are individually generated then it becomes relatively easy, if required, to modulate each with its own phase and/or amplitude modulated waveform. If phase (and hence frequency) modulation is required then it could be of advantage to use a source as described in co-pending application No 8716458 in which the frequency stability of the source is not inherently dependent on the degree of frequency modulation used.

The units forming the parts of the circuits described above may all be constructed using commonly available components and conventional technology; in particular, the use of chip technology would overcome the expense of the multiplicity of similar circuits required for modulation generation and control. Those skilled in the art will readily appreciate that there are many variations of the embodiments described which are within the scope of the invention.

CLAIMS

1. A circuit for generating a modulated signal comprising:

means for generating a carrier structure consisting at each of one or more frequencies of two or more carrier component signals having a different phase from one another;

means for generating at least one multiple spectral line modulation structure at each of one or more modulating frequencies for each carrier component signal, each modulation structure having an individual spectral distribution;

means for controlling the phase and amplitude of the separate lines in each modulation structure;

means for multiplying each carrier component signal with a different modulation structure; and

means for adding the resulting corresponding spectral lines to synthesise the required frequency, phase and amplitude of the modulated signal.

2. A circuit according to Claim 1 in which the means for generating a modulation structure includes means for generating harmonics of an applied modulating sinusoid and means for separately controlling the phase and amplitude of each harmonic component and for adding each component so generated.

3. A circuit according to either preceding claim in which the means for generating a harmonic structure includes a frequency division circuit for applying to a pulsed input signal to generate sub-harmonics of said signal and means for adding the modulating components so produced after separate control of their amplitude and phase.

4. A circuit according to any preceding claim including means for generating multiple spectral line modulation structures which are identical but out of phase with one another.

5. A circuit according to any preceding claim in which the carrier structure consists of pairs of carrier component signals in quadrature phase with one another and which are multiplied with a different one of two multiple spectral line modulation structures.

6. A circuit according to Claim 5 including means for generating two multiple spectral line modulation structures which are identical but in quadrature phase with one another.

7. A circuit according to Claim 6 including means for generating two sets of multiple spectral line modulation structures having in-phase and quad-phase components, and means for adding the in-phase components of each set with the quad-phase component of the other set and for multiplying the resulting modulation structures with the carrier component signals.

8. A circuit substantially as hereinbefore described with reference to Figure 4 of the drawings.

Published 1989 at The Patent Office, State House, 66/71 High Holborn, London WC1R 4TP. Further copies may be obtained from The Patent Office. Sales Branch, St Mary Cray, Orpington, Kent BR5 3RD. Printed by Multiplex techniques ltd, St Mary Cray, Kent, Con. 1/87